Physicochemical and Optical Characterization of Aerosol Fields from Coastal Breaking Waves

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LONG TERM GOALS

Our intent is to establish an improved understanding of the properties and factors that control the physicochemistry of marine aerosol and the implications for the optical properties of the marine aerosol in a coastal environment. These include issues related to the source, transformation and evolution of marine aerosol physicochemistry including sulfate but with particular interest in sea-salt from breaking waves.

OBJECTIVES

Our objectives are to link in-situ measurements of aerosol chemistry and optical properties at a coastal site in order to establish the mechanisms that control the aerosol concentration and size distribution under diverse conditions. Most measurements will be carried out at our Bellows Air Force Base (BAFB) Research Tower located on the east coast of Oahu (Fig 1a). The whew east form the tower into the prevailing trades winds (Fig. 1b) shows both the shoreline and the reef with braking waves near the horizon. Evolution of the sea-salt form this "line source" about 1.5km off shore is an object of study. Emphasis will be on vertical structure over the lower tens of meters of the atmosphere. We propose to do this in conjunction with a lidar located at the site and using a variety of in-situ measurements. We will use a portable instrument package that includes aerosol total condensation nuclei (CN) counter, aerosol total and submicrometer light scattering using nephelometery, and aerosol optical particle counters including laser optical particle counters (OPC's) and forward scattering spectrometer probe (FSSP) for particle sizes from 0.1 to 50 micrometers. We will deploy this package on the tower using a winch system that will allow us to operate it at various altitudes from 0 to 20m. We will also deploy it aboard a modified Piper SENECA for offshore profiles. Additional studies that characterize aerosol production and size spectra from individual breaking waves will also be carried out.

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Fig. 1 a,b The 20m BAFB coastal tower as seen looking east toward the ocean and view from the tower looking east toward the shallows upwind reef with breaking waves about 1.5km away (near center of photo just below horizon).

A related activity includes reducing the size of components of this package and instrumenting a Remotely Piloted Vehicle (RPV) for coastal flights near surface and within line of sight. This will include a nephelometer, a custom optical particle counter, a custom CN counter, GPS, avionics and a master computer all in a 20lb payload.

The measurements proposed are designed not only to provide information on the size and concentration of the atmospheric aerosol but also to measure size dependent properties of the aerosol that we have found to be related to both its chemistry and optical effects. For many remote regions, the submicron aerosol mass is usually dominated by a mix of sulfuric acid or sulfate while sea-salt dominates the coarse particle mass. In coastal environments the latter can be the dominant light scatterer at both visible and infrared wavelengths. Our intent is to carry out measurements and analysis that can quantitatively link the variability in the concentrations of these species to the aerosol optical properties in a coastal environment.

APPROACH

Because we are developing capabilities in several areas we have spent most of the first year fabricating and testing various instrument packages and systems. These are described briefly below along with the personnel involved.

- Coastal measurements are made at the BAFB tower **(Fig.1)**. Our portable van at the base of the tower also included a 3 wavelength TSI nephelometer and data system including meteorological variables. A differential mobility analyzer can also be installed along with our Lagged Aerosol Grab (LAG) chamber for obtaining samples form individual breaking waves. Periodically we also employ our thermally conditioned optical particle counter to establish the size distribution sea-salt and sulfur aerosol including the relative neutralization of the submicron sulfur mass by inferring the $NH_4^+/SO_4^=$ ratio. A forward scattering spectrometer probe FSSP-300 also sizes aerosol from 0.3 to 50um.

Fig. 2. Aerosol inlet, venturi and temperature/humidity sensors are mounted atop Seneca passenger door. Aerosol instrument package is visible behind the passenger seat.

- Extended aerosol fields and vertical profiles are studied using our 6 seater SENECA aircraft. It is rented but we have purchased doors that install with our sampling probes and sensors that are installed just before flights **(Fig 3.)**. The instrument package **(Fig. 4)** has been refined by graduate student Ken Moore (it is also used on the tower at Bellows) is installed where the middle two seats normally are located. We have added a GPS and a mass flowmeter to maintain isokinetic flow in the sampling inlet. The latter is aspirated by a door mounted venturi **(Fig 3.)**.

A Microtops sunphotometer is also used to obtain aerosol optical depth at three wavelengths and column ozone. These are used to get differential properties over altitude ranges during descent. This package has been used to obtain aerosol microphysics and optical properties between about 3km and 25m in the vicinity of BAFB. Additional studies in cooperation with the lidar are to be carried out this year.

Fig. 4 View of aerosol package during installation with inlet plumbing to two nephelometers to right of box, CN counters to their left and Met 1 particle counters below. Datalogger , GPS and microcomputer attach in front of box for operator use after installation is complete. An external forward scattering spectrometer probe (FSSP-300x) is mounted below the fuselage and provides ambient size distributions (0.3-20um or an optional 0.5-40nm).

- We are also soon to take delivery of an RPV and will instrument it for aerosol microphysics studies. It will be operated generally within about 2km radius of the BAFB tower **(Fig 2)**. It will have a nephelometer, an optical particle counter, CN counter, GPS, met sensors, color video camera and transmitter, a computer, autopilot and receiver on board.

WORK COMPLETED

Our activities have involved developing all of the above capabilities and some limited experiments designed to test them and establish a preliminary data base. Following the order mentioned above these are:

1) The BAFB site was refurbished and laboratories rearranged in order to accommodate the lidar van (Dr. Shiv Sharma, Dr. Barry Lienert) and to allow lidar measurements coincident with our in-situ sampling.

2) A remote controlled winch arrangement was engineered and installed (Mark Rosen, tech.) to allow us to profile over the height of the tower using our portable instrument package. Preliminary experiments have been carried out with both lidar and portable systems.

3) The SENECA custom experiment doors and portable instrument package were completed and flown on several test flights including of the coast of BAFB.

4) Specifications for the RPV aircraft have been submitted to the vendor BTA and a prototype was completed. Test flights were carried out near Los Angeles earlier this year and it flew successfully with the engine configuration, autopilot and 25lb payload specified. The ordered unit is to be delivered by December 1998. The wings, fuselage, landing gear, servos, engine installation were complete in October and the final tail section will be completed in November for delivery and testing. Formal negotiations with the Air Force over the past 6 months have now provided us with permission to fly the RPV from the BAFB coastal airstrip near the tower during the next several years.

5) Instrumentation for the mini-Sheddon (B.T.A.) RPV is under development. It has a 3.2m wingspan and weighs about 26kg including an instrument payload of 10kg. It flies at 20-40 m/s and as high as 3.5km. We will operate it in line of sight mode with onboard B.T.A. autopilot and azimuth control with the instrumentation below controlled with a PC-104 computer.

- The nephelometer, BTA autopilot, BTA azimuth control are in hand.

- We have also built and successfully tested the high resolution color video camera **(Fig. 5)** transmitter and receiver system including the audio channel that will be used for a data downlink.

- The new CN counter is a custom version of the TSI (Thermo-Systems Inc. Mod. 3010) that has been reduced to weigh only 2.2lb and employs a small TTL count processor developed by Dr. Chuck Brock (NASA). Machining and integration of CN components are complete including a finned cooling section that will be external to the RPV **(Fig. 5).** We are in the process of developing the computer hardware needed for final control and integration.

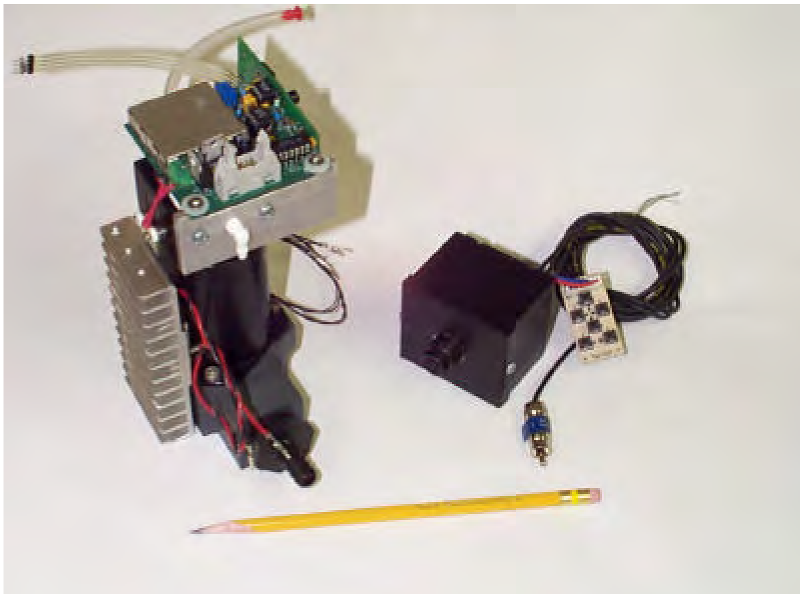


Fig.5 Our 2.2lb stripped TSI 3010 counter (detector courtesy of TSI) on left and showing NASA pulse counter card (courtesy Dr. Chuck Brock) and cooling fins that will extend through fuselage. On right is our TV quality color video camera with annotation keypad.

- We have a contract with Ms. Electron Inc. (Norm Ahlquist, Seattle) to develop a miniature pulse height analyzer for a solid state laser for an optical particle counter (OPC) intended to size sea-salt over the 0.5-10um range. A prototype has just been delivered and is working successfully with a larger instrument. The miniature RPV OPC hardware and software is to be delivered by January 1999 and expected to weigh about 2.5 lbs.

- Tests are being made of a 0.5lb ultrasound device (Senix Corp.) that can determine distance to 2cm accuracy within a range of about 15m. If we are successful in our tests we will develop it into a fail safe control device to prevent the aircraft from approaching too close to the ocean surface during our low altitude passes (<10m).

- We are looking into a miniature upwelling microspectrometer (Alcprecision) for ocean color that could also be integrated into our package. However, we are waiting until existing instruments are mounted and flow before extending our capabilities.

SCIENTIFIC RESULTS

We have successfully tested our portable instrument package at the Bellows tower **(Fig. 1a)** for investigations of vertical profiles in this coastal setting and for intercomparisons with the recently co-located lidar instrument. The profiling studies of light scattering with both nephelometer measuring both total and submicron scattering with a 20sec time constant **(Fig. 6)** , often show smooth gradient over the 20m tower altitude with a rapid decrease near 7m that we believe is due to coastal breaking waves **(see Fig. 1b).** However, concurrent measurements shown from the faster response CN (1Hz) counter reveal that peaks in CN occur in smaller scale patches and indicate that the 20sec averaging in the nephelometer may reflect

a mean condition but does not reveal the spatial and temporal details (patchiness) of the sea-salt plume structure. Provision for faster response profile measurments from the nephelometer are being made in order to better characterize the structure.

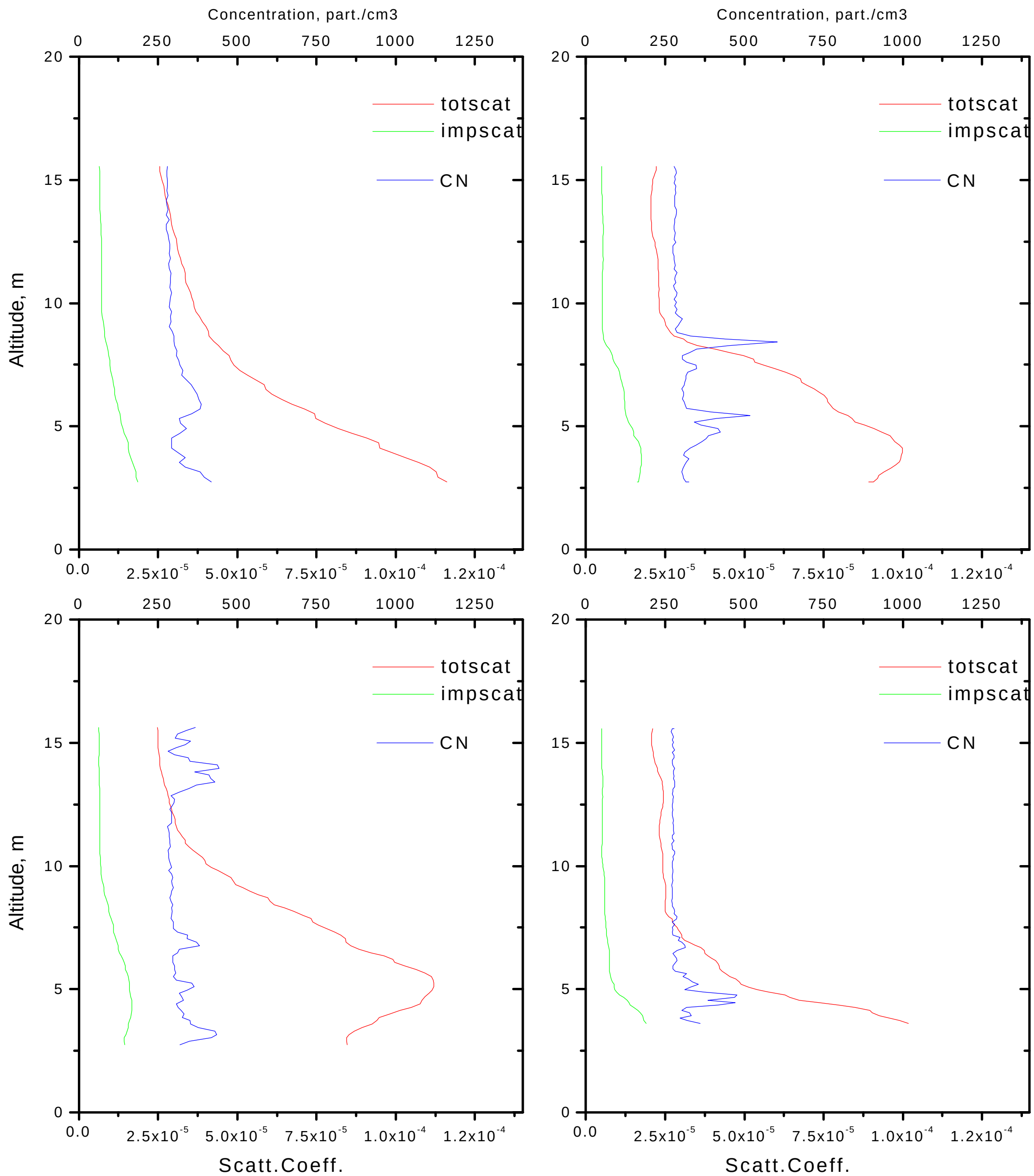


Fig 6. Four profiles of total light scattering, submicrometer light scattering and CN.

A time series for measurements made at the bottom and top of the tower **(Fig. 7)** indicate the temporal variability in both light scattering and CN. The data from the bottom of the tower show the elevated values and rapid variability due to small waves on the nearby shore (about 20m away but the less frequent and smaller events for the data at the top of the tower we believe are associated with patches of sea-salt aerosol from waves breaking about 1.5km offshore in the shallow reef area) **(Fig 1b)** .

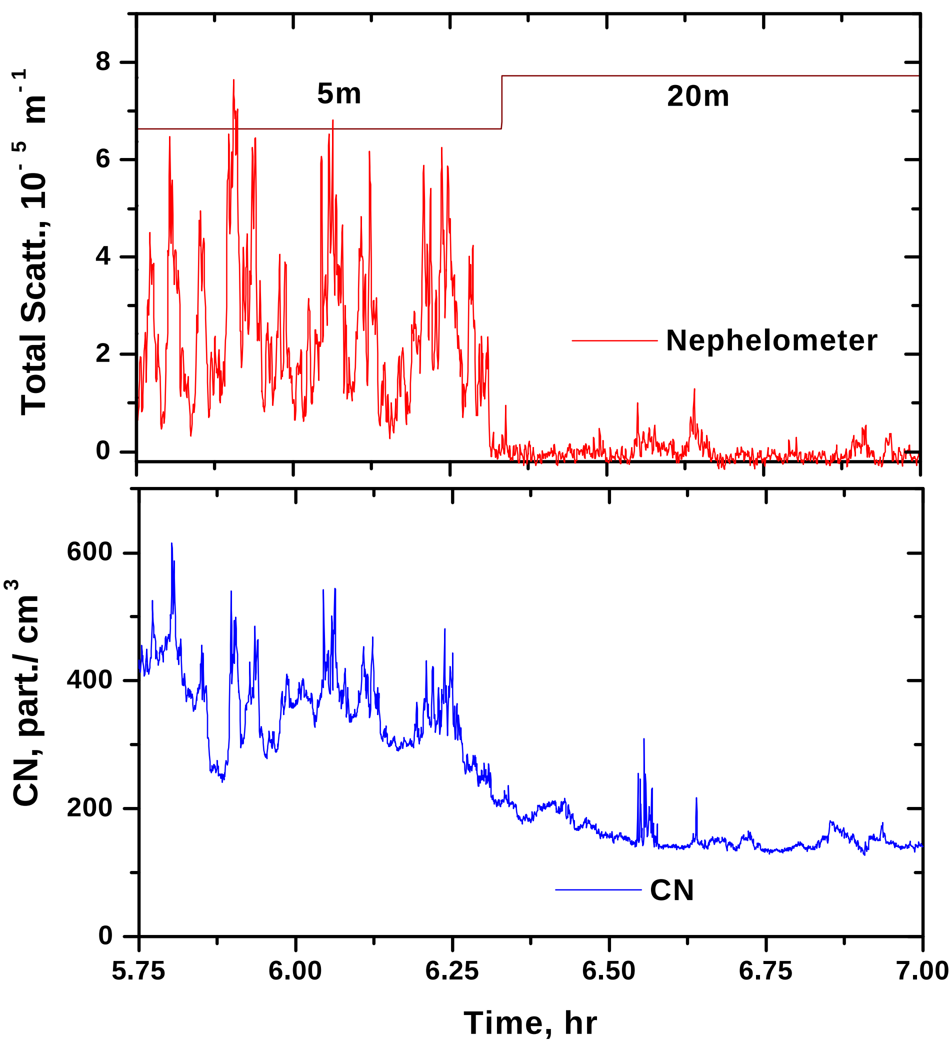


Fig. 7. A sequential time series of scattering and CN data taken over approximately 80 minutes first at the bottom and then at the top of the tower. Large excursions in both measurements reflect near shore breaking waves while smaller excursions at the top of the tower are due to the offshore breaking waves. Both sources are evident in Fig. 1b.

Lidar images obtained in collaboration with Dr. S. Sharma and Dr. B. Lienert reveal the patchy horizontal structure of such plumes from this offshore breaking wave area as they move toward our sampling site **(Fig.8)**. This structure of these patches and associated aerosol microphysics and optics will be the subject of continued studies.

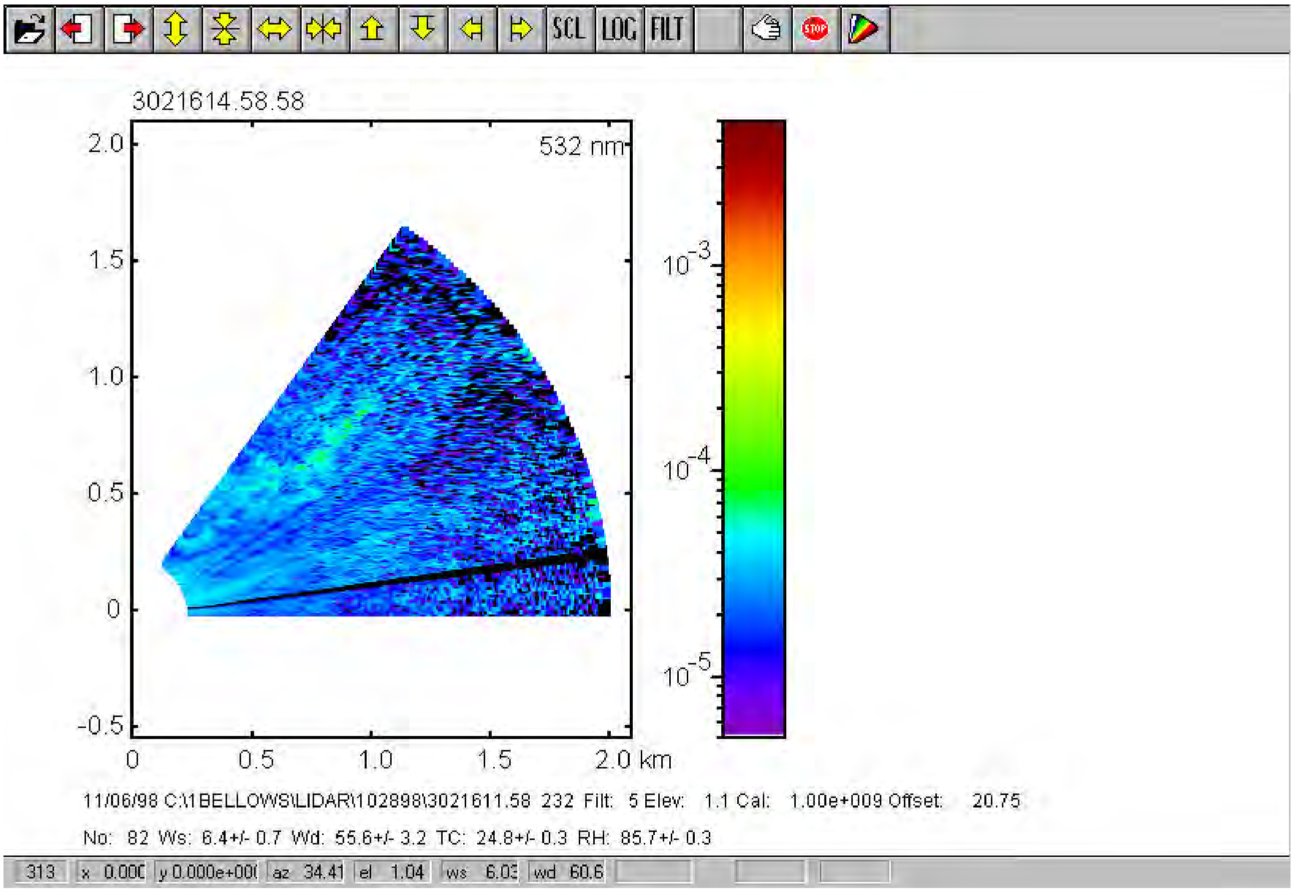


Fig. 8 This horizontal lidar scan at about 10 m reveals the patchy structure of aerosol plumes from the offshore breaking waves (Fig. 1b) and which give rise to the patchy structures shown in Fig. 7 near the tower top.

We have also recently initiated concurrent sampling for comparison to lidar retrievals under conditions with more variable winds, frequent shower activity and high humidity. These are at times associated with reduced visibility due to a combination of rain (including virga – small drizzle droplets that evaporate during their fall to the surface), elevated sea spray from winds and braking waves, and high RH that increases water uptake by the aerosol and results in increased scattering cross sections. While these are not favorable sampling conditions for some instruments they are cases where understanding the nature of reduced visibility is of interest. A preliminary case is shown here that includes the change in coastal aerosol properties associated with a squall moving onshore over a shallow offshore reef with breaking waves. An example of a lidar image **(Fig. 9)** reveals the cloud and subcloud squall structure as it moved onshore (see the Sharma et al. report for more complete lidar images of this event). The image also shows a low cloud deck and developing shallow layer of surface aerosol downwind of the reef area.

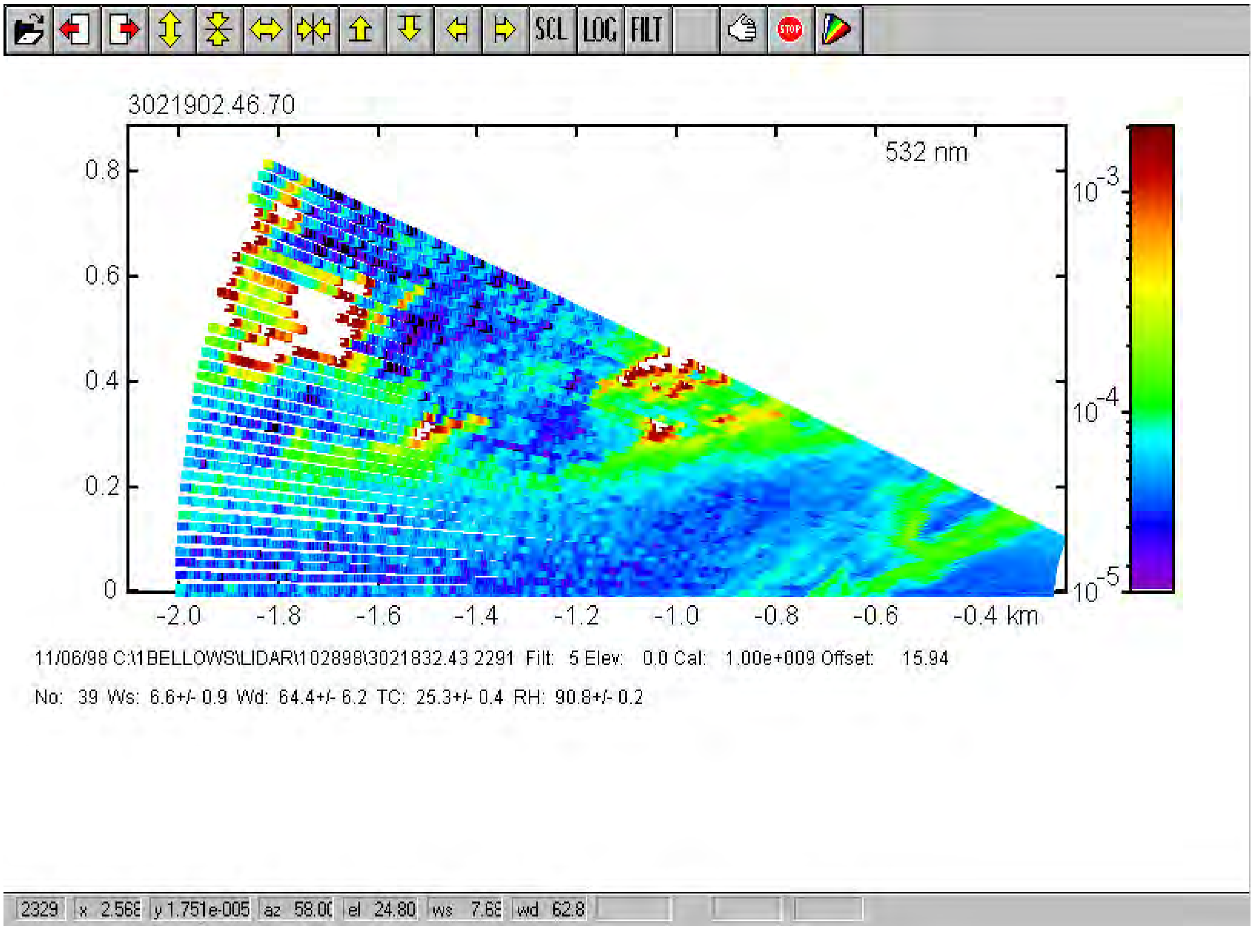


Fig. 9. A vertical lidar scan showing low clouds and patchy virga falling from a squall about 0.2 to 0.8km out to sea from the site.

A time series of aerosol measurements that reflect the passage of a squall over the BAFB tower is shown in **Fig. 10** for the light scattering coefficient and integral particle area from the FSSP. Increases of wind speed from 8 to 13 m/s were observed and relative humidity (RH) went over 90%. Near 19.2 hr there is a rapid increase in particle surface area and in light scattering seen by the nephelometer. **Figure 11** is a time series of the FSSP size distribution that shows a dramatic increase in large particle surface area particularly in sizes above 10um that are too large to be "seen" by the nephelometer. Interestingly the scattering continues to increase to maximum values during the period of decreasing larger particle sizes measured by the FSSP. The broadening of the distribution for sizes below 10um may play a role in this behavior or fluctuations in RH and wind speed and direction that may influence the performance of either instrument. Further exploration of these situations with both lidar and in-situ data is planned.

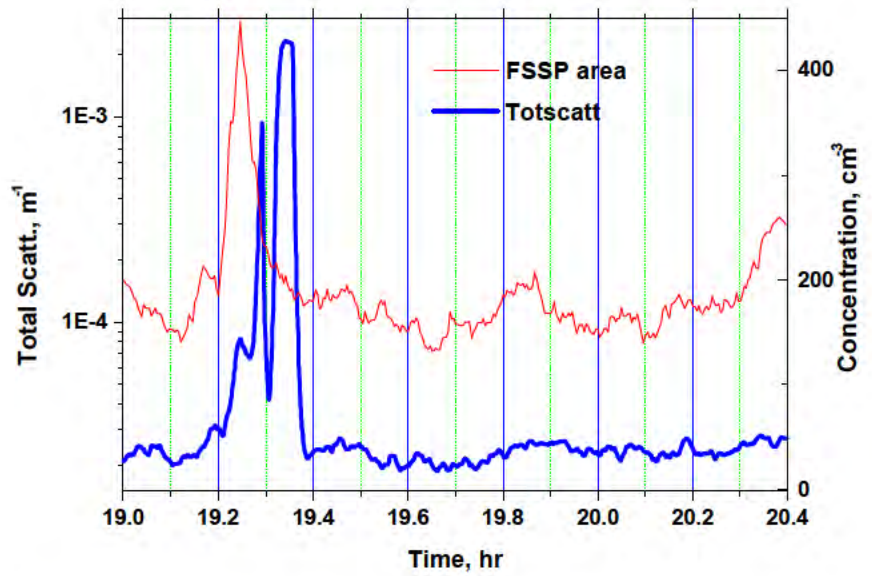


Fig. 10. A time series of light scattering coefficient and integral particle area from the FSSP that reflect the passage of a squall over the BAFB tower.

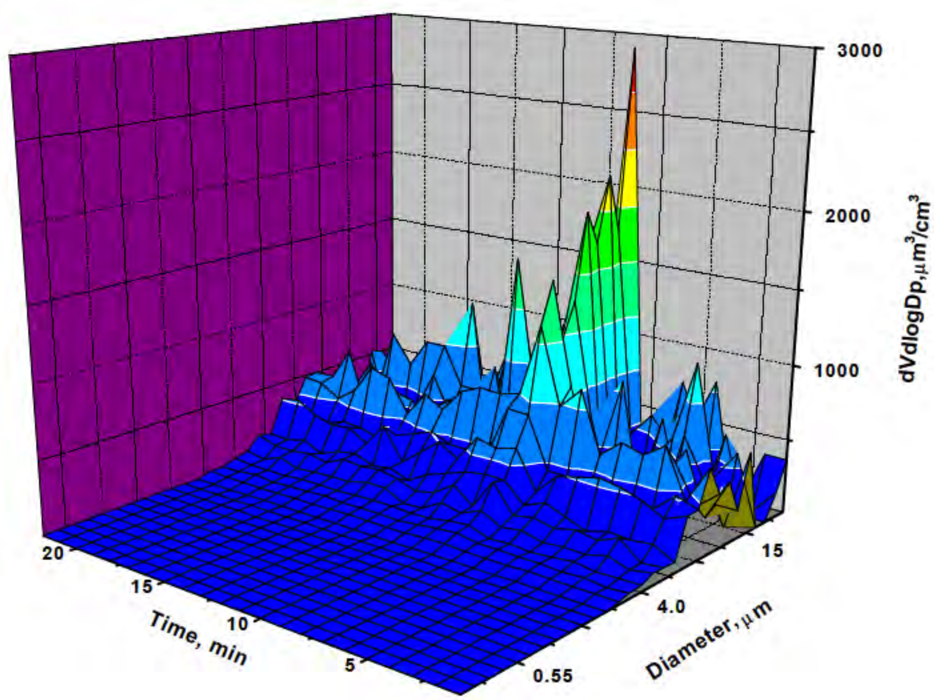
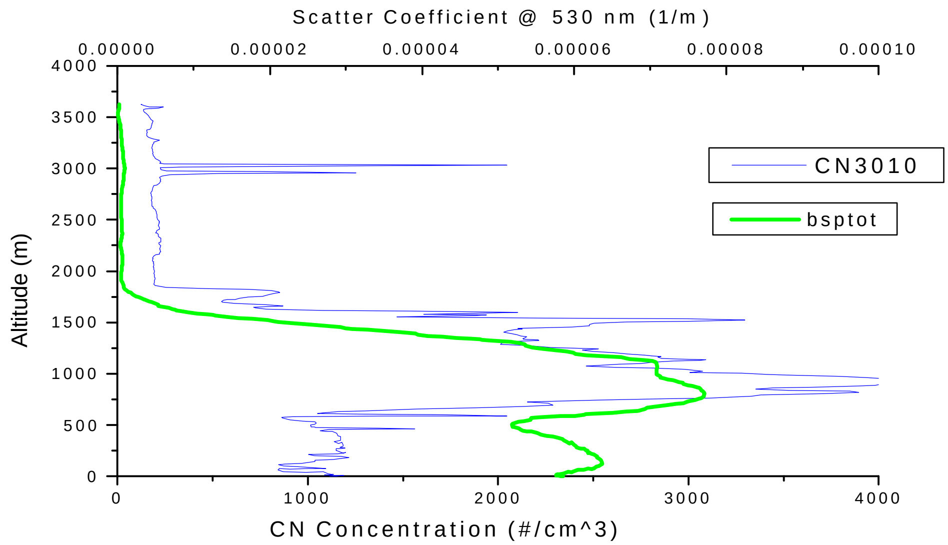


Fig. 11. Time series of the FSSP size distributions including elevated values during squall.

The same tower instrument package has been also tested aboard the SENECA aircraft for profiling studies. Examples of vertical profiles of aerosol light scattering and CN are shown for two distinct cases over the ocean near Hawaii. Nephelometer light scattering data for Feb. 10 (Fig. 12) show a layer of enhanced scattering is present between 500m and 1,500m altitude corresponding to the peak aerosol layer from the volcanic plume originating from Kiluaea volcano. A separate layer between the surface and 700m is clearly evident in the CN data and also in the nephelometer data but less pronounced. The scattering extinction on Feb. 11 (Fig. 13) shows more typical open ocean conditions with low scattering values above about 2km even Athough CN are higher aloft than in the marine boundary layer (MBL), indicating the dominance of small particles with little contribution to optical depth above that altitude.



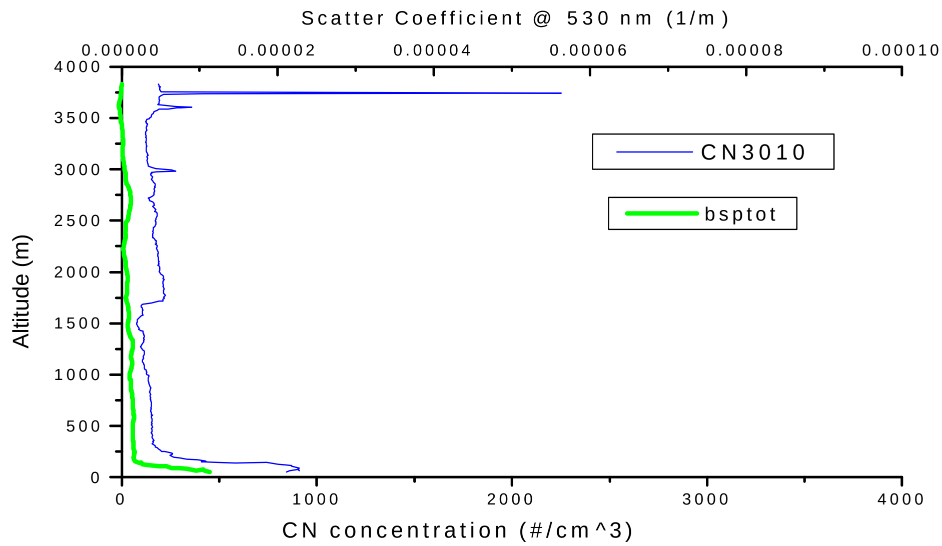


Fig. 12,. Vertical profiles of light scattering and aerosol number concentration (CN) for volcanically influenced and clean marine cases.

IMPACT/APPLICATION

The results of our linking aerosol microphysics to optical properties and lidar backscatter in a coastal setting provide concurrent data on the scales and variability in the aerosol properties that dominate its optical effects. These measurements will be used to model aerosol properties related to their radiative effects and their dependence upon parameters incfluencing aerosol production This information can also be used to validate and refine operational optical models such as NOVAM. Continued application of this approach to our data in the clean central Pacific including the coastal and breaking wave environment will should provide new inputs for regimes where the existing NOVAM model has less reliability. The linkages of aerosol physical, chemical and optical properties being explored during the current Hawaiian coastal measurements will improve modeling of boundary layer aerosol fields from breaking waves.

RELATED PROJECTS

Below I list work ongoing in conjunction with the Marine Boundary Layer (MBL) ARI of the physical oceanography and marine meteorology sections of ONR

1) We are actively involved in coordinated activities with Dr. S. K. Sharma's Lidar project (as indicated above). This is ONR project #N000149610317 and more can be found under his filed report opss0061.doc.

2) Some of our aircraft studies aboard the SENECA aircraft are being carried out with Dr. John Porter as part of our NASA grant. **Aircraft Radiation and Aerosol Measurements near Hawaii: Satellite Validation at the MOBY Buoy and HOTS Site**; (co. P.I. with J. Porter), NASA.